MATHEMATICS DEPARTMENT
RESEARCH SUMMARIES AY 2004

CARLOS F. BORGES – *Associate Professor*

Research Project Summary
TOTAL LEAST SQUARES FITTING OF ORDERED DATA WITH POLYNOMIAL SPLINES
C. F. Borges, Associate Professor of Mathematics
Sponsor: Unfunded

Objective: To develop fast and numerically stable algorithms for fitting polynomial splines to ordered data with minimal error in the total least-squares sense.

- **Summary**: This unfunded effort is a continuing research project. The idea is to fit parametric polynomial spline curves to ordered data to get the best possible fit. Unlike traditional least-squares methods we assume that errors may occur in both the x and y directions. Moreover, we allow the data to be completely general - in particular, it does not have to be functional in nature, it may overlap itself or change directions without restriction. All that is required is an ordered set of points in the plane. This year I have focused on rapid algorithms for computing the QR decomposition of a generalization of the Vandermonde matrix. I have had mixed results – better speed but a loss of accuracy. More research is needed.

DOD Key Technology Area: Scientific Computation

Keywords: Curve Fitting, Data Compression, and Approximation Theory.

Research Project Summary
Brief Investigation of Configural Mine Warfare Theory
C. F. Borges, Associate Professor of Mathematics
Sponsor: RADM Pearson

Objective: To perform a brief preliminary investigation of the configural theory of mine warfare with an eye toward developing some basic tools using the theory.

Summary: This effort looked at the configural theory of mine warfare. A significant part of the effort was collecting and reading much of the work to date in configural mine warfare. At the end of that time a summary report was written giving a carefully documented analytical solution to a simple, but essential, mine warfare scenario. It is shown that a wide variety of analysis is possible and that these yield a variety of

insights into the problem. A proposal for more in depth follow-on work has been submitted.

DOD Key Technology Area: Modelling and Simulation

Keywords: Mine Warfare, Configural.

DAVID CANRIGHT – *Associate Professor*

Research Project Summary

ADVANCED RADAR DIGITAL SIGNAL PROCESSING USING COTS COMPUTERS WITH RECONFIGURABLE ARCHITECTURES

Douglas J. Fouts, Professor
Department of Electrical and Computer Engineering
David Canright, Associate Professor
Department of Applied Mathematics
Sponsor: National Security Agency

OBJECTIVE: To design, construct, debug, and test a hardware and software interface between a radar and a commercial-off-the-shelf (COTS) computer with a reconfigurable architecture in order to perform advanced digital signal processing of radar signals using the reconfigurable computer. A second objective is to develop a fully pipelined version of the Advanced Encryption Algorithm (AES) for the same COTS computer with a reconfigurable architecture.

See the **FAR** *of Professor Douglas Fouts (ECE) for the Project Summary relating to the first objective; the summary below relates to the second objective.*

SUMMARY: The specific reconfigurable computer chosen for this work is an SRC-6E from SRC Computer Corp. The reconfigurable part of this system uses Virtex II field-programmable gate arrays (FPGAs). Constraints in this system precluded a fully pipelined implementation of AES using a table lookup approach for the crucial S-Box step. Instead, another approach to the S-Box was developed, replacing the table with a direct calculation using a compact arrangement of logic gates. Mathematically, this involves using subfields for the Galois arithmetic, and different alternatives in each subfield result in 432 different implementations of this method. From these, the most compact was identified and optimized, yielding an S-Box circuit 20% smaller than the most compact previously known. This allowed a fully pipelined AES on a single Virtex II chip; the same approach may be useful for other hardware-limited implementations of AES, e.g., smart cards.

PUBLICATIONS:
D. Canright, "A Very Compact Rijndael S-box," Naval Postgraduate School Technical Report, NPS-MA-04-001, December 2004.

PRESENTATIONS:
D.J. Fouts, K. Macklin, D. Zulaica, and R. Duren "Electronic Warfare DSP Applications Using Reconfigurable Computers", Classified Technology Update Course, U.S. Naval Postgraduate School, July, 2004.

D. Fouts, K. Macklin, and D. Zulaica, "Electronic Warfare DSP Applications Using Reconfigurable Computers", 2004 Military Applications of Programmable Logic Devices Conference, Washington, D.C., September, 2004.

THESES DIRECTED:
Macklin, Kendrick R., "Benchmarking and Analysis of the SRC-6E Reconfigurable Computing System", MSEE Thesis, March 2004.

Macklin, Kendrick R., "Suitability of the SRC-6E Reconfigurable Computing System for Generating False Radar Images", MSCS Thesis, June 2004.

KEYWORDS:
Reconfigurable computing, cryptography, AES, Rijndael.

DONALD A. DANIELSON – *Professor*

BUCKLING OF SHIP GRILLAGES WITH BULB FLAT STIFFENERS

D.A. Danielson, Professor
Sponsor: Naval Surface Warfare Center – Carderock Division

OBJECTIVE: Use analytical formulas and finite element models to calculate the buckling loads of ship grillages with bulb flat stiffeners.

SUMMARY: A series of multi-bay steel grillages typical of ship structures have recently been tested to collapse at the Naval Surface Warfare Center. Some of the grillages are made of plate panels strengthened longitudinally with bulb flat stiffeners. In this report a theory is developed to predict the failure stresses of bulb flat grillages. It is postulated that a grillage buckles initially into either a tripping or a column mode. Formulas are given for the critical buckling stresses associated with these modes. The

theory is compared to the experiments and found to give usually conservative predictions.

PUBLICATIONS:
Danielson, D. A., Wilmer, A., "Buckling of Stiffened Plates with Bulb Flat Flanges," *International Journal of Solids and Structures*, Vol. 41, pp. 6407-6427, 2004.
Danielson, D. A. "Failure of Stiffened Plates with Bulb Flat Flanges," Naval Postgraduate School Technical Report, NPS-MA-04-002, September 2004.

KEYWORDS: Structure, Ship, Grillage, Stiffener, Buckling

FARIBA FAHROO – *Associate Professor*

Research Project Summary
Real-Time Computation of Trajectories for Hypersonic Launch Vehicles
Fariba Fahroo, Associate Professor of Mathematics
Sponsor: Unfunded

Objective: Developing numerical algorithms for computing trajectories for re-entry launch vehicle in real-time, as well as studying the numerical properties of these algorithms such as convergence and stability.

Summary: In this project computational methods for generating optimal trajectories for re-entry vehicles subject to 3 DOF nonlinear dynamics were considered. Mathematically the problem was formulated within the framework of nonlinear and possibly non-smooth optimal control theory. Issues such as numerical stability and convergence of a class of numerical methods, pseudospectral methods, were considered. In addition real-time implementation of the methods was also studied.

Publications (Journal):

1) Ross, I. M., and Fahroo, F., ``Pseudospectral Methods for Optimal Motion Planning of Differentially Flat Systems,'' *IEEE Transactions on Automatic Control,* Vol. 49, No. 8, 2004, pp. 1410-1413.
2) Ross, I. M. and Fahroo, F., ``Pseudospectral Knotting Methods for Solving Optimal Control Problems,'' *Journal of Guidance, Control and Dynamics,* Vol. 27, No. 3, 2004, pp. 397-405.
3) Ross, I. M. and Fahroo, F., " Issues in the Real-Time Computation of Optimal Control," Accepted (November 2004) to appear in the *Journal of Mathematical and Computer Modelling,* Pergaman Press.

Publications (Conferences-Presentations):

1) Ross, I. M., Fahroo, F., "Discrete Verification of Necessary Conditions for Switched Nonlinear Optimal Control s ystems,} *the Proceedings of the American Control Conference,* Boston, MA, June 2004.
2)

DOD Key Technology Area: Space Vehicles

Keywords: Trajectory Optimization, Guidance, Pseudospectral methods.

Research Project Summary

Natural Adaptive Observers for 2nd –O Distributed Parameter Systems

Fariba Fahroo, Associate Professor of Mathematics

Sponsor: Unfunded

This is work that is with collaboration with Prof. Michael Demetriou at WPI.

Publications: Conference Papers and Presentations in CY04

1) M. Demetriou, and F. Fahroo, " A Natural Observer-Based Adaptive Controller for Structurally Perturbed Second Order Distributed Parameter Systems, " *the proceedings of the MTNS Conference*, Leuven, Belgium, July 2004.

2) M. Demetriou, and F. Fahroo, An Adaptive Control Scheme for a Class of Second Order Distributed Parameter Systems with Structured Perturbations, *the proceedings of the IEEE Conference on Decision and Control,* The Bahamas, December 2004.

Research Project Summary

Development of On-Line Footprint Generation Algorithms for Space Access Vehicles with Control Failures

Fariba Fahroo, Associate Professor of Mathematics

Sponsor: Unfunded

Objective: To develop fast and accurate numerical methods for determining the largest reachable set (footprint) for a reusable launch vehicle under actuator failure.

Summary: This research project was the continuation of the work done at the AFRL in 2002. The ultimate goals of this research were to develop advanced guidance and control algorithms for hypersonic and reusable launch vehicles. One application is in the area of determining reachable regions by a reentry or un-powered hypersonic vehicle experiencing control effector failures. This problem was formulated as a parameter dependent optimal control problem and was solved using a numerical

package developed at NPS by (Mike Ross and the PI). Future goals of the project will involve designing an adaptive reconfigurable control system for the X-40A vehicle to support a flight-test demonstration of an integrated adaptive guidance and control system.

Publications: Conference Papers and Presentations in CY04

1) Fahroo, F. and Doman, D., `` A Direct Method for Approach and Landing Trajectory Reshaping with Failure Effect Estimation,'' *Proceedings of the AIAA Guidance, Navigation and Control Conference,* Providence, RI, August 2004.

Presentations (for delivery in CY04):

1) Fahroo, F. and Doman, D., `` A Direct Method for Approach and Landing Trajectory Reshaping with Failure Effect Estimation,'' presented at the 2004 AIAA Conference on Guidance, Navigation and Control, August 2004, Providence, RI.

DOD Key Technology Area: Space Vehicles

Keywords: Trajectory Optimization, Guidance, Footprint Generation, Reusable launch Vehicles, Pseudospectral methods.

Research Project Summary
Computational Mathematics Program
Fariba Fahroo, Associate Professor of Mathematics
Sponsor: AFOSR

Objective: To manage the computational math program at the Air Force Office of Scientific Research in Arlington, VA.

Summary: This program manages a multi-million dollar basic research effort at the university and air force labs level to develop improved numerical and mathematical modeling and simulation capabilities for Air Force needs.
The program also supports the national Air Force program in high performance computing. The duties involve managing the portfolio by knowing the latest trends in computational algorithm developments (as related to the Air Force), visiting the PIs, holding program review meetings, maintaining inter-agency and inter-service contacts with other DOD funding agencies and increasing the portfolio's exposure internally and externally to attract more funding for more research programs.

CHRIS FRENZEN – *Associate Professor*

PHYSICAL DERIVATION OF LANGMUIR-CHILD SPACE CHARGE LIMITED EMISSION

Chris Frenzen, Associate Professor
Department of Applied Mathematics
Naval Postgraduate School
Sponsor: unsponsored research

OBJECTIVE: We develop a simple capacitive model for Langmuir Child space charge limited emission using vacuum capacitance, conservation of energy, and conservation of charge.

SUMMARY: The fundamental Child–Langmuir limit on the maximum current density in a vacuum between two infinite parallel electrodes is one of the most well known and often applied rules of plasma physics. We develop a simple model using vacuum capacitance, conservation of energy, conservation of charge to derive the Child–Langmuir space-charge-limited emission. This capacitive model provides physical insight into the origins of the well known (voltage) ^3/2/ (gap distance) ^2 scaling of the classical current density and does not require the solution of the nonlinear differential equation normally associated with the Child–Langmuir formulation. In addition, the full space charge- limited solution is reproduced without imposing the condition that the electric field be driven to zero at the cathode surface.

PUBLICATIONS: to appear in 2005 in American Journal of Physics

THESES DIRECTED: Carr, C. G., `` SPACE CHARGE LIMITED EMISSION STUDIES USING COULOMB'S LAW'', June 2004.

WILLIAM B. GRAGG – *Professor*

Research Project Summary
Research in Computation
William B. Gragg, Professor of Mathematics
Sponsor: Unfunded

Objective: I have no funded research projects. This is not to say that I do not continually try to do (high quality) research in scientific computing. See my publication list which is part of my CV. There are always more problems than solutions, but the ones that last are the ones that are elegantly solvable. For

instance, in a paper dedicated to me on my 65th birthday, Lothar Reichel et. al. showed how to compute the zeros of linear combinations of polynomials orthogonal on the real line, or the unit circle in the complex plane, in O(n^2) operations. The first had been an open problem for many years. The solution was elegant and simple. The solution applicable to the usual polynomial problem, when the polynomial is expressed as a linear combination of the powers, depends strongly on my "uhqr" (unitary Hessenberg QR) algorithm. These algorithms are fundamental, and brand new (soon to appear in J Comput Appl Math)!

WEI KANG – *Associate Professor*

COOPERATIVE CONTROL OF MULTI-SETP MANUFACTURING SYSTEMS

Wei Kang, Associate Professor
Department of Mathematics
Sponsor: Intel Corp

OBJECTIVE: The objective of the proposed research is twofold: to develop software for implementation of the adaptive run-to-run control method developed during the first year of the project; and to push the research to a larger scale for multiple step processes. The goal is to develop control architecture and feedback algorithms to achieve cooperative control of semiconductor manufacturing process with multiple processing steps.

SUMMARY: Working with engineers from Intel, we successfully identified the variables and steps that are critical to the overall performance of the multi-step manufacturing process. Based on real manufacturing data, a three layer cooperative control architecture is developed. Mathematical model is developed for each layer of the process based on real data and important multiple input and output parameters. Cooperative control law is now under development to optimize the cost functions, under the constraints and based on real-time information. Meanwhile simulations based on real data has bee carried out for lower layer subsystem control.

PUBLICATION:

Journal Papers:

1. 1. B. Hamzi, W. Kang and J.-P. Barbot, Analysis and Control of Hopf Bifurcations, SIAM J. on Control and Optimization, Vol. 42, No. 6, pp. 2200-2220, 2004.
2. A. J. Krener, W. Kang and D. Chang, Control Bifurcations, IEEE Trans. on Automat. Contr., Vol. 49, pp1231-1246, 2004.
3. W. Kang, N. Xi, J. Tan and Y. Wang, Formation Control of Multiple Autonomous Robots: Theory and Experimentation, Intelligent Automation And Soft Computing, Volume 10. No. 2, 2004, pp. 1-17.

4. B. Hamzi, W. Kang and A. J. Krener, The Controlled Center Dynamics, SIAM J. Multiscale Modeling & Simulation, to appear.
5. W. Kang, M. Song, and N. Xi, Bifurcation Control, Manufacturing Planning, and Formation Control, Automatica Sinica, 2005, to appear.
6. W. Kang, N. Xi, J. Tan, Y. Zhao, and Y. Wang, Coordinated Formation Control of Multiple Nonlinear Systems, Journal of Control Theory and Applications, to appear.

Conference Proceedings:

1. W. Kang and J. Mao, Adaptive Modeling and H_∞ Control for Photolithography Manufacturing Process, Proc. American Control Conference, Boston, MA, June, 2004.
2. Q. Gong, I.M.Ross, W. Kang and F. Fahroo, Convergence of Pseudospectral Methods for Constrained Nonlinear Optimal Control Problems, IASTED International Conference on Intelligent Systems and Control, Honolulu, Hawaii, August, 2004, pp. 209--214.
3. B. Hamzi, W. Kang, and A. J. Krener, The controlled center dynamics of discrete time control bifurcations, NOLCOS04, Stuttgart, September, 2004.
4. W. Kang and J. Mao, An Adaptive Model for the Control of Critical Dimension in Photolithography Process, Proc. IEEE Conference on Decision and Control, December, 2004.
5. W. Kang and J. Mao, Robust Control of Lithographic Process in Semiconductor Manufacturing, Proc. SPIE Symposium on Microlithography, March, 2005.
6. B. Hamzi, W. Kang, and A. J. Krener, Stabilization of Discrete Time Systems with a Fold or Period-Doubling Control Bifurcation, IFAC World Congress, Praha, Spain, 2005, to appear.

PRESENTATION:

W. Kang, CD Control With Adaptive Modeling and Robust Feedback, Invited Presentation, High Volume Manufacturing Research Committee, Intel Corp., October, 2004.

BENY NETA– *Professor*

Research Project Summary

A Study of Lateral Boundary Conditions for The NRL's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS)

Beny Neta, Professor of Mathematics

Sponsor: NPS

OBJECTIVE: The treatment of lateral boundaries in regional models has been a perennial problem since the early days of numerical weather prediction. In a limited-area model the lateral edges are not physical boundaries of the flow but constitute

artificial constraints imposed by computational considerations. Hence they do not have a physical counterpart. We must impose conditions at these artificial boundaries in order to solve the problem in an efficient and accurate manner.
We propose here to continue our work on high order non-reflecting boundary conditions for the dispersive Klein-Gordon equation. We intend to extend our new schemes to the nonlinear shallow water equations.

Keywords: Mesoscale, limited-area model, perfectly matched layers, COAMPS.

DoD Key Technology Areas: Software.

PUBLICATIONS

1. V. van Joolen, B. Neta, and D. Givoli, "A Stratified Dispersive Wave Model with High-Order Non-Reflecting Boundary Conditions," *Computers and Mathematics with Applications*, **48**, (2004), 1167–1180.

2. I.M. Navon, B. Neta, M.Y. Hussaini, "A perfectly matched layer approach to the linearized shallow water equations models," *Monthly Weather Review*, **132 No.6**, (2004), 1369 – 1378.

3. V. van Joolen, B. Neta, and D. Givoli, "High-Order Higdon-Like Boundary Conditions for Exterior Transient Wave Problems," *International Journal Numerical Methods in*
Engineering, accepted for publication.

4. V. van Joolen, B. Neta, and D. Givoli, "High-Order Boundary Conditions for Linearized Shallow Water Equations with Stratification, Dispersion and Advection," *International Journal Numerical Methods in Fluids*, **46(4)**, (2004), 361–381.

5. J.G. Taylor, B. Neta, and P.A. Shugart, "An Analytical Model That Provides Insights into Various C2 Issues," *Proceedings of the 2004 Command and Control Research and Technology Symposium.*

6. D. Givoli, B. Neta, and V.J. van Joolen, "Application of Higdon non-reflecting boundary conditions to shallow water models," in *Proceedings ICOSAHOM 2004,* Brown University, Providence, RI, 21-25 June 2004 (T. Hagstrom and T. Warburton, eds.)

PRESENTATIONS

1. J.G. Taylor, B. Neta, and P.A. Shugart, "An Analytical Model That Provides Insights into Various C2 Issues," Proceedings of the 2004 Command and Control Research and Technology Symposium.

2. D. Givoli, B. Neta, and V.J. van Joolen, "Application of Higdon non-reflecting boundary conditions to shallow water models," in Proceedings ICOSAHOM 2004, Brown University, Providence, RI, 21-25 June 2004 (T. Hagstrom and T. Warburton, eds.)

THESIS DIRECTED

LT Brad G. Harris, USN, Analysis of Lateral Boundary Effects on Inner Domain of COAMPS, September 2004.

GUILLERMO OWEN – *Professor*

Research Project Summary
Mathematical Models of Terrorism and Low-Intensity Conflict
Guillermo Owen, Professor of Mathematics
Sponsor: Department of Defense Analysis

Professors McCormick and Owen have developed game-theoretic models for the problem of counter-proliferation; on this topic, one article was submitted for publication. They have also developed models of low-intensity conflict, and particularly, civil war. One article was submitted and accepted for publication. They are currently studying the problem of state sponsors of terrorism. An article is in preparation.

PUBLICATIONS

G. McCormick and G. Owen: "A Mathematical Model of Counter-proliferation, with Multiple Entrants", to appear in International Game Theory Review, 2005.

(with G. McCormick): "Factionalism, Violence, and Bargaining in Civil Wars," Homo Œconomicus, 2004, 361-390.

PRESENTATIONS

G. McCormick and G. Owen: "A Mathematical Model of Counter-proliferation, with Multiple Entrants,"
Free University of Amsterdam, June 29 2004.

Research Project Summary
Mathematical Models of Search

Guillermo Owen, Professor of Mathematics
Sponsor: Department of Defense Analysis

This project is funded through the Department of Defense Analysis. Owen and Professor Gordon McCormick of DA are co-Principal Investigators. Professors McCormick and Owen have developed game-theoretic models for search; on this topic, one article was submitted for publication.

PUBLICATIONS

(with G. McCormick): "Manhunting," submitted to a volume of articles in honor of Martin Shubik,

Research Project Summary
Theory of Games and Applications
Guillermo Owen, Professor of Mathematics
Sponsor: Unfunded

Objective: This is an unsponsored project, on which Professor Owen has worked with mathematicians at the Complutense University in Madrid, Spain, and at the University of Hamburg, Germany. He has published an article dealing with centrality in social networks, and submitted a second one for publication. He also submitted an article on reduced games and consistent values, which was accepted for publication.

CRAIG RASMUSSEN – *Associate Professor*

Research Project Summary
Modeling Target Acquisition, Tracking, and Loss in MOUT Using Graphs
Craig Rasmussen, Associate Professor of Mathematics
Sponsor: TRADOC Analysis Center, Monterey

Objective: To model target acquisition, tracking and loss in Military Operations in Urban Terrain (MOUT) with graphs, and to then apply analysis techniques such as those from the theory of random graphs to gain insights for the Objective Force (OF) and Future Combat System (FCS), and for future simulations.

Summary: This research developed urban target acquisition models that could be substituted for existing physics-based or other computationally expensive combat simulation algorithms, resulting in faster simulation runtime with an acceptable loss of aggregate simulation accuracy. Specifically, this research explored (1) the adaptability

of probability of line of sight estimates to urban terrain; (2) the use of cumulative distribution functions to model the outcomes when a set of sensors is employed against a set of targets; (3) the use of Markov Chains and Event Graphs to model the transition of a target among acquisition states; and (4) how a system of differential equations may be used to model the aggregate flow of targets from one acquisition state to another. Items (3) and (4) were not developed in depth. Item (1) was very successful and was subsequently passed to AAMSA for further development.

Publications: Mlakar, Joseph A., "Aggregate Models for Target Acquisition In Urban Terrain", NPS Thesis (Dual MS in OR/MA), Advisors Craig Rasmussen and LTC Thomas Cioppa.

DOD Key Technology Area: Modeling and Simulation

Keywords: MOUT, Graph Models

CLYDE SCANDRETT – *Professor*

Research Project Summary
Mine Warfare Symposium
P.I.: C. Scandrett
Sponsor: Naval Postgraduate School

Objective: To include as operating funds in hosting the 6th international Symposium on Technology and the Mine problem which was held May 9-13, 2004 at the naval Postgraduate School.

Summary: The Symposium was a success, and will likely continue on an every-other-year basis at the Naval Postgraduate School. Funds were used to defray costs accrued by hosting such a large symposium, and for publishing a proceedings and CD's of the Symposium.

Publications:
Proceedings of the Sixth Symposium on Technology and the Mine Problem – 2004

Presentations:
None.

DOD Key Technology Area: Sensors, Electronics, and Battlespace Environments and Weapons

Keywords: Mines, Mining, Undersea Warfare